Forecasting Coastal Habitat Distributions through Fusion of Earth Observations, Process Models and Citizen Science: A Climate Change Adaptation Tool for the NOAA National Estuarine Research Reserve System

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Abstract:
Estuarine managers need ecological forecasting tools to prepare for the potential impacts of future climate change. With funding from the NASA Ecological Forecasting program, and in partnership with the NOAA National Estuarine Research Reserve System (NERRS), we tested the viability of integrating Earth and in situ observations with a model of tidal marsh elevations to forecast spatially-explicit coastal habitat response to sea level rise. Our research area focused on a brackish marsh, Rush Ranch, one of two sites in the San Francisco Bay NERR, one of a national network of 28 reserves that operate a System-wide Monitoring Program to assess habitat responses to sea level rise. Using a site-calibrated version of the Marsh Equilibrium Model (MEM3), we tested the sensitivity of the model's projections for mineral and organic accretion based on two primary variables: total suspended sediment and peak aboveground biomass. Earth observations of these two variables from Landsat 8, AVIRIS and World View-2 sensors will be compared for their utility to generate spatially-explicit model outputs. Elevation responses for four zones (unvegetated, high, middle, and low marsh) will be incorporated into a spatial model to produce maps for assessing habitat sustainability and potential for landward migration. As a core member of one of 5 NOAA-wide pilot projects for sentinel sites, SF Bay NERR is actively implementing national elevation monitoring protocols. If the remotely sensed data retrieval is sufficiently robust, this approach will be tested incrementally for broader application in other coastal areas. The ability to integrate inexpensive synoptic spectral data to populate and validate accretion models could expand opportunities to project marsh sustainability both locally and nationally.

Marsh Elevation Model:

MEM incorporates both physical and biological feedbacks to changing relative elevations. MEM describes feedbacks among the plant community, sediments, and tides and that explains the dependency of the relative elevation of a tidal marsh on rising sea level. The model assumes a calibrated rate of belowground organic matter accretion and that suspended solids carried by tides settle as a function of the:

- concentration of suspended sediment (mg/L)
- standing biomass density (g/m^2)
- duration of flooding (tide gauge).

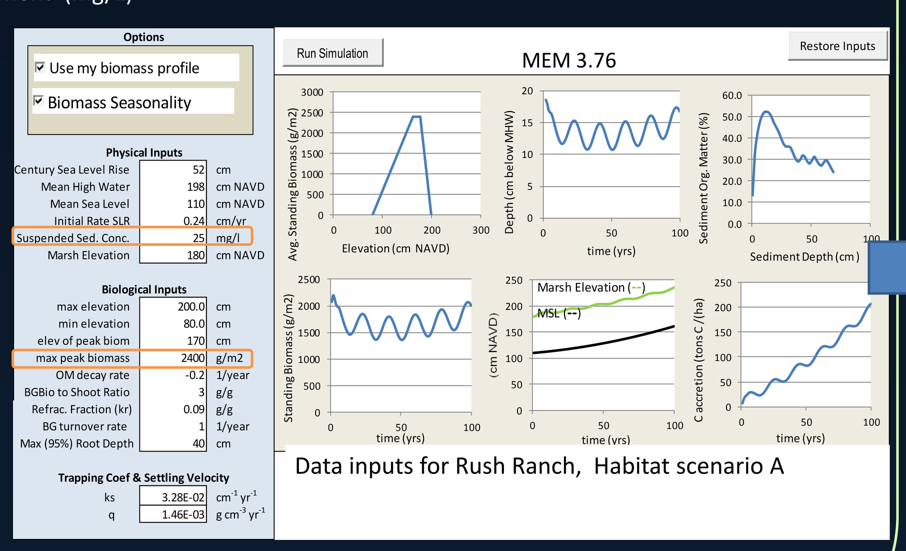
MEM is the most effective model.

- Testable
- Empirically-calibrated (soil core)
- User-friendly (Excel-based)

NOAA-NERR sites already have the required *in situ* data.

MEM has been successfully applied to a broad range of sites and SLR.

MEM outputs can be used for habitat modeling as well as carbon sequestration, and soon CH_4 flux.



Data inputs for Rush Ranch, Habitat scenario A

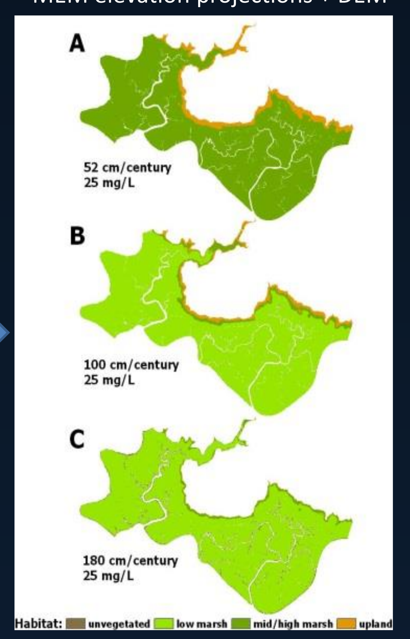
Two most important inputs may be remotely sensed

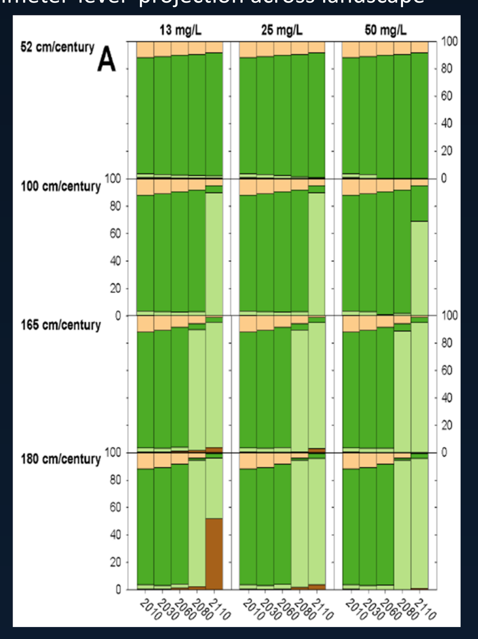
Habitat Distribution Model:

e.g. Schile et al. 2014, PLOS

100-yr habitat projections with ArcGIS Model Builder

MEM elevation projections + DEM = centimeter-level projection across landscape





Good for acreage, patch distribution

Good for sensitivity analyses (management)

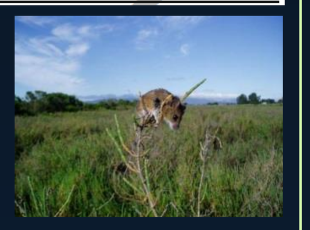
Marsh elevations have major ecological and biogeochemical implications.

Species Distribution Model:

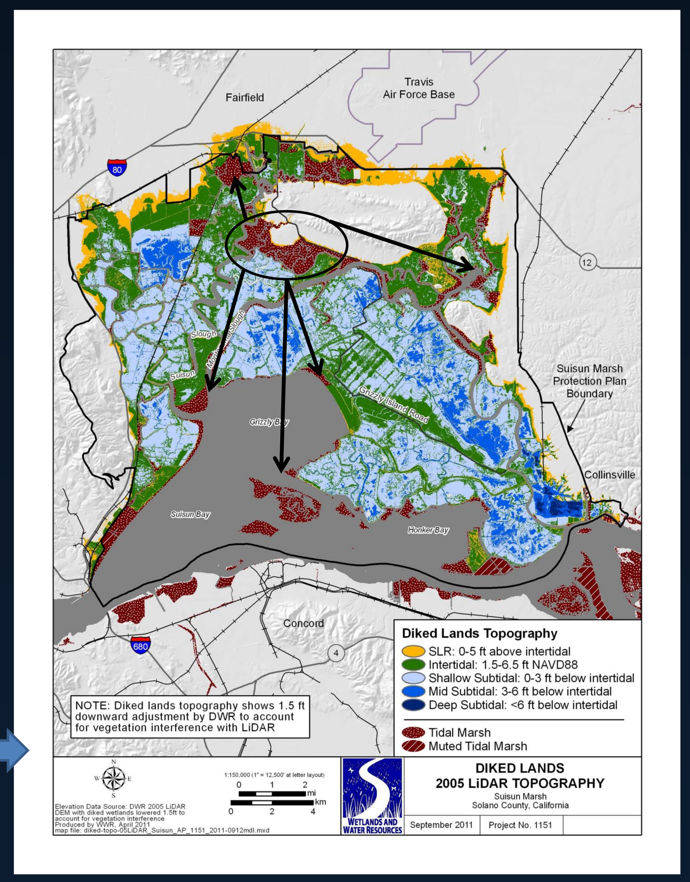
Vegetation and wildlife habitat by elevation

e.g. Swanson et al., 2013
Takekawa et al., 2011

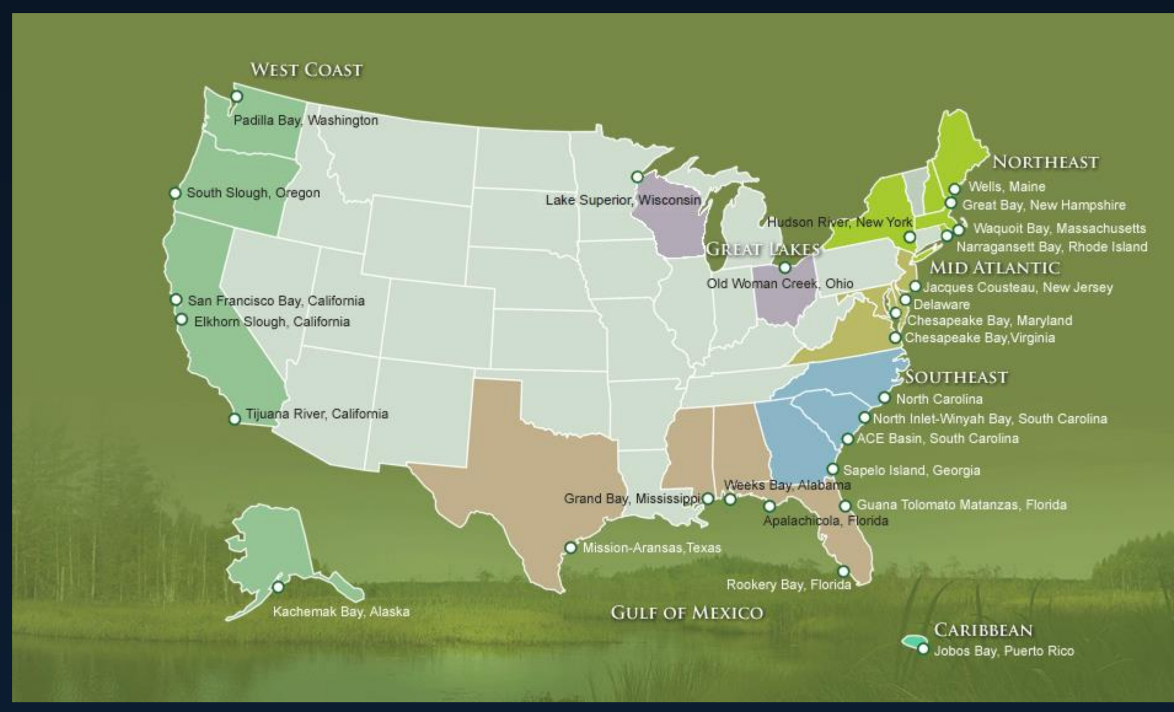
	Evaluation criteria	Explanation
Vegetation	% area where $z^*>0.3$	Pickleweed (*S. pacifica*) habitat
	% area where $0<z^*<0.3$	Cordgrass (*S. foliosa*) habitat
Salt marsh harvest mouse (*R. raviventris*)	% area where $z^*>1$	Nesting habitat and refuge during extreme events
California clapper rail (*R. longirostris obsoletus*)	% area where $z^*>1$	Nesting habitat and refuge during extreme events
	% area where vegetation heights are >20 cm above MAT	Refuge from predation



Objective, quantifiable, regional-scale projections of current and future habitat quality for endangered species

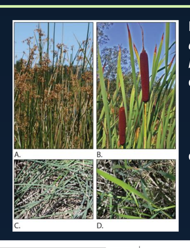


Goal = Applicability to all 28 NERR sites, as evaluated by data and algorithm performance

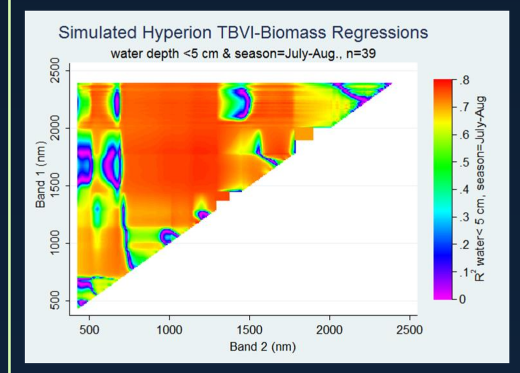


Peak Aboveground Biomass

Field-verified testing of spectral models

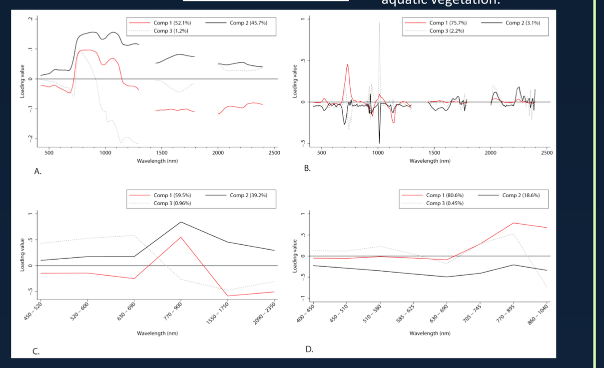


Photos of
a. *Schoenoplectus acutus*,
b. *Typha latifolia*,
c. . above-canopy photo of *S. acutus* displaying substrate of dead standing vegetation, and
d. d. above-canopy photo of *Typha* spp. displaying substrate of dead standing vegetation and floating aquatic vegetation.



1. Vegetation indices

R^2 values for regressions of the square root of wetland biomass collected in mid-summer, low-water conditions to all NDVI-type two-band vegetation indices derived from 164 simulated Hyperion satellite bands. The best index was $TBVI_{1790,1164}$ with an R^2 of 0.78. A TBVI based on wavelengths 1565 nm and 865 nm (the mid-points of the SWIR-1 and NIR Landsat 8 bands) also successfully estimated biomass, with R^2 of 0.75, indicating the feasibility of this sensor to estimate wetland vegetation biomass (Byrd et al. 2013)



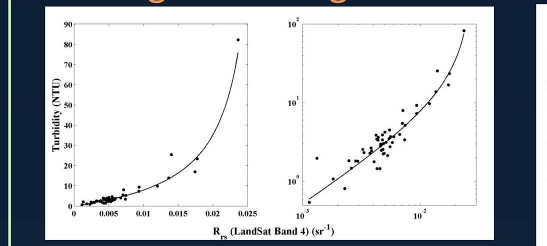
2. Partial Least Squares Regression

Loadings of the first three partial least squares factors plotted against wavelength, excluding wavelength regions associated with strong water absorption features for partial least squares regression of aboveground biomass with simulated a) Hyperion, b) Hyperion first derivative reflectance, c) Landsat 7 and d) World View-2 bands derived from field spectrometer reflectance data. The percent variability in measured biomass captured in each component is provided for each plot (Byrd et al. RSE in press).

Suspended Sediment Concentration (mg/L) or TSM

Field verified spectral indices: 3 approaches

1. Single band algorithms



2. Band ratios

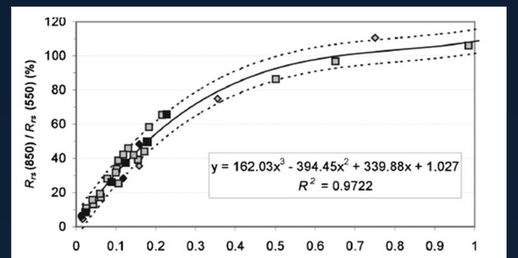
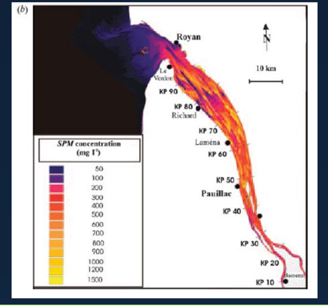
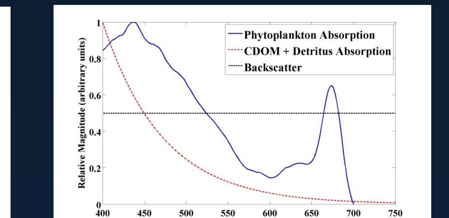


Figure 4. Ratio of reflectance [R_{rs}(850 nm)/R_{rs}(550 nm)] plotted against *TSMc*. Date of measurements: July (rhombus), August (circles) and September (squares) 2000 (grey points) and 2001 (black points). Plot of the third order polynomial regression and the ±7% reflectance ratio uncertainty which includes all points in the range 0.010–1.000 g l^{-1}.



3. Matrix Inversions



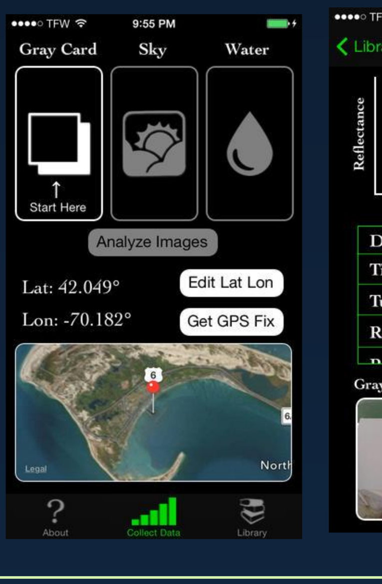
$$\begin{bmatrix} \exp[(\lambda_1-\lambda_g)^2/2g^2] & \exp[-S(\lambda_1-\lambda_d)] & (\lambda_b/\lambda_1)^n v(\lambda_1) \\ \exp[(\lambda_2-\lambda_g)^2/2g^2] & \exp[-S(\lambda_2-\lambda_d)] & (\lambda_b/\lambda_2)^n v(\lambda_2) \\ \exp[(\lambda_3-\lambda_g)^2/2g^2] & \exp[-S(\lambda_3-\lambda_d)] & (\lambda_b/\lambda_3)^n v(\lambda_3) \end{bmatrix} \cdot \begin{bmatrix} a_{ph}(\lambda_g) \\ a_d(\lambda_d) \\ b_{bt}(\lambda_b) \end{bmatrix} = \begin{bmatrix} h(\lambda_1) \\ h(\lambda_2) \\ h(\lambda_3) \end{bmatrix} \qquad (11b)$$

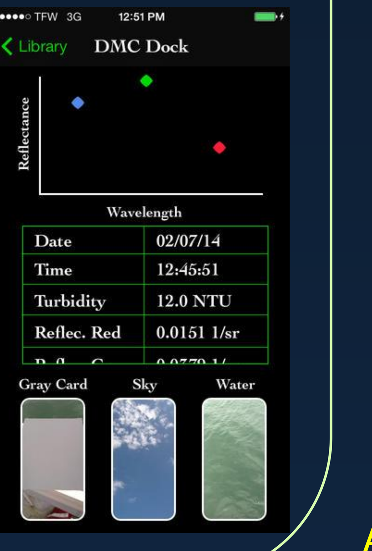
These approaches reflect a range of applicability for different quality and quantity of sensor and field data inputs.

Citizen Science

Hydrocolor App allows public collection of quantitative estimates of turbidity and spectra, which can be used to validate maps.

- Easy to use
- Created by Co-PI Leeuw
- IPhone application (available online February 2014).
- Calibrates reflectance in three wave lengths (Red, Green, Blue) using an 18% gray card.
- Calculates turbidity (NTU)





Future Steps:

We are currently determining the level of NOAA data support needed to develop a NASA-NOAA partnership for implementation.

This tool is directly responsive to NOAA-NERR strategic coastal planning.

Future Applications will include:
C modeling
Water quality monitoring
Vegetation mapping

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